

Effects of Nonionizing Radiation on the Central Nervous System, Behavior, and Blood: A Progress Report

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This paper presents a progress report on the U. S. research which has been designated as collaborative research with the Soviet Union to study the biological effects of nonionizing radiation on the central nervous system, behavior, and blood. Results of investigations to study the effects of microwaves on isolated nerves, synaptic function, transmission of neural impulses, electroencephalographic recordings, behavior, and on chemical, cytochemical and immunological properties of the blood are presented. Specifically, the effects of microwave exposure on chick brain and cat spinal cords, on EEG patterns of rats, on behavior of neonatal rats exposed during development, on behavior of adult rats, on behavior of rhesus monkeys and on the pathology, hematology, and immunology of rabbits will be reported in a summary format. Much of the information is new and has not been published previously.

Introduction

In December 1976, the United States and the Soviet Union agreed to include in the collaborative program on environmental health the problem area, "Study of the Biological Effects of Environmental Physical Factors." The first topic to be included in this problem area was the effects of nonionizing radiation on the central nervous system and behavior. Presently, the major portion of the cooperative research is concerned with the biological effects of microwave radiation. Research from the National Institute of Environmental Health Sciences, Environmental Protection Agency, Bureau of Radiological Health-FDA, University of California, Los Angeles, and University of Washington are

included in the U. S. portion of the cooperative program. This paper presents a progress report of the results obtained during the first year from this research.

Project 1. Study of Effects of Microwaves on Isolated Nerves, Synaptic Function, and Transmission of Neural Impulses

Adey at UCLA has been studying the effects of electromagnetic radiation on brain cells of cats and chicks (*1*). He and his colleagues have found that weak sinusoidal electric fields modify the calcium efflux from freshly isolated chick and cat cerebral tissues bathed in Ringer's solution at 36°C. Following incubation (30 min) with radioactive calcium ($^{45}\text{Ca}^{2+}$), each sample, immersed in fresh solution, was exposed for 20 min to fields at 1, 6, 16, 32, or 75 Hz, with electric gradients of 5, 10, 56, and 100 V/m in air. $^{45}\text{Ca}^{2+}$ efflux in the solution was then measured in 0.2 ml aliquots and compared with efflux

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Table 1. Effects of ELF fields on $^{45}\text{Ca}^{2+}$ efflux from the cat cortex.

Electric gradient, V/m	Frequency, Hz	$^{45}\text{Ca}^{2+}$ efflux, mean \pm SEM		No. of paired samples	<i>t</i>	<i>p</i>
		Field	Control			
10	6	0.948 \pm 0.023	1.000 \pm 0.023	23	1.296	N.S.
	16	0.983 \pm 0.037	1.000 \pm 0.034	29	0.302	N.S.
	32	1.006 \pm 0.054	1.000 \pm 0.036	16	0.108	
56	1	0.974 \pm 0.054	1.000 \pm 0.036	23	0.386	N.S.
	6	0.855 \pm 0.034	1.000 \pm 0.043	21	2.600	< 0.05
	16	0.874 \pm 0.025	1.000 \pm 0.026	24	3.402	< 0.01
	32	0.090 \pm 0.034	1.000 \pm 0.040	21	1.704	N.S.
	75	0.932 \pm 0.026	1.000 \pm 0.033	22	1.600	N.S.
100	6	1.00 \pm 0.025	1.000 \pm 0.032	21	0.016	N.S.
	16	0.965 \pm 0.033	1.000 \pm 0.025	29	0.830	N.S.

Table 2. Effects of ELF fields on $^{45}\text{Ca}^{2+}$ efflux from the chick forebrain.

Electric gradient, V/m	Frequency, Hz	$^{45}\text{Ca}^{2+}$ efflux, mean \pm SEM		No. of paired samples	<i>t</i>	<i>p</i>
		Field	Control			
5	6	0.923 \pm 0.036	1.000 \pm 0.036	30	1.450	N.S.
	16	0.933 \pm 0.041	1.000 \pm 0.041	27	1.144	N.S.
	32	0.945 \pm 0.041	1.000 \pm 0.041	27	0.974	N.S.
10	1	0.943 \pm 0.041	1.000 \pm 0.038	26	1.021	N.S.
	6	0.866 \pm 0.029	1.000 \pm 0.037	26	3.069	< 0.01
	16	0.849 \pm 0.026	1.000 \pm 0.031	38	3.726	< 0.01
	32	0.913 \pm 0.038	1.000 \pm 0.037	27	1.633	N.S.
56	1	1.028 \pm 0.042	1.000 \pm 0.038	26	0.515	N.S.
	6	0.882 \pm 0.031	1.000 \pm 0.030	37	2.681	< 0.05
	16	0.889 \pm 0.035	1.000 \pm 0.034	36	2.489	< 0.05
	32	0.942 \pm 0.038	1.000 \pm 0.038	26	1.518	N.S.
100	6	0.928 \pm 0.028	1.000 \pm 0.029	36	1.735	N.S.
	16	0.995 \pm 0.037	1.000 \pm 0.037	28	0.092	N.S.

from unexposed control samples. Field exposures resulted in a general trend toward a reduction in the release of preincubated $^{45}\text{Ca}^{2+}$. Both frequency and amplitude sensitivities were observed. Maximum decreases occurred at 6 and 16 Hz (12–15%). Thresholds were around 10 and 56 V/m for cat and chick tissues, respectively (Tables 1 and 2). Similar but nonsignificant trends occurred during other field exposures. All results were statistically compared with matched samples of controls. Tissue gradients could not be measured, but estimates were of the order of 0.1 $\mu\text{V}/\text{cm}$. It is important to note that the susceptibility of the electrochemical equilibrium in the neuronal membrane is dependent upon both frequency and amplitude of the sinusoidal field. Although 6 and 16 Hz fields at 56 V/m produced a significant effect, 100 V/m fields did not produce a significant effect.

As a result of these studies, Adey and his colleagues (2) have exposed neonatal chick brain to amplitude-modulated 147 MHz vhf fields of a power density of 1–2 mW/cm^2 and measured the effect on

$^{45}\text{Ca}^{2+}$ efflux from the isolated forebrain (Fig. 1). The results show that for tissue bathed in physiological medium the unmodulated radiations and fields modulated at 0.5 and 3 Hz failed to induce any significant changes in the $^{45}\text{Ca}^{2+}$ efflux, by comparison with unirradiated control brains (three repetitions, 30 samples for each condition). By contrast, there was a progressive increase in the $^{45}\text{Ca}^{2+}$ efflux from the brains exposed to the fields modulated at 6 Hz (40 samples, 10.1%, $p < 0.05$), 9 Hz (30 samples, 14.3%, $p < 0.05$), 11 Hz (50 samples, 16.0%, $p < 0.01$), and 16 Hz (80 samples 18.5%, $p < 0.01$). These effects gradually decline at higher frequencies. Exposures to 20-Hz sinusoidal modulation lead to a small increase of the $^{45}\text{Ca}^{2+}$ efflux (30 samples, 9.5%, $p < 0.05$). The results obtained with 25-Hz modulation (30 samples, 6%) were not statistically significant, and the fluxes observed with 35-Hz modulation did not differ from the controls.

The results with poisoned brains were identical to those observed simultaneously for the samples

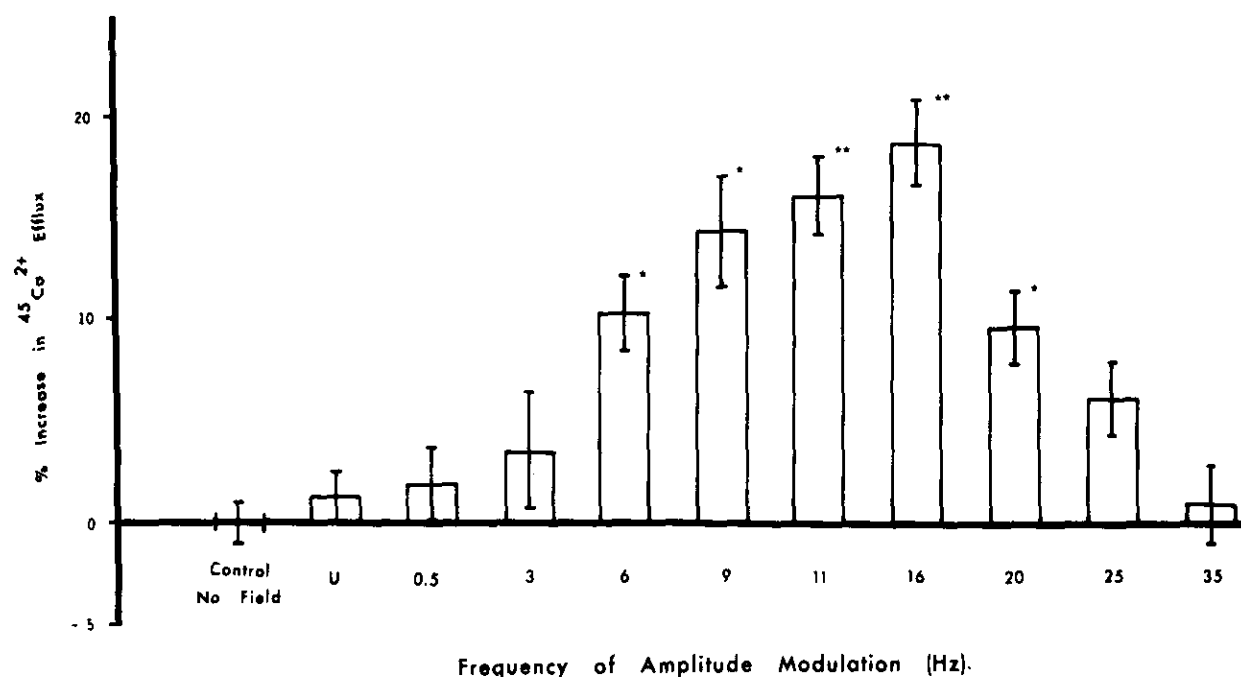


FIGURE 1. Effects of amplitude modulated 147 MHz vhf fields on the $^{45}\text{Ca}^{2+}$ efflux from isolated forebrain of the neonatal chick (* $p < 0.05$, ** $p < 0.01$).

Table 3. $^{45}\text{Ca}^{2+}$ efflux from the chick forebrain at 450 MHz, amplitude modulation 16 Hz.

Field intensity, mW/cm ²	$^{45}\text{Ca}^{2+}$ efflux, mean \pm SD ^a		N	t
	Field	Control		
0.5	1.212 \pm 0.268	1.000 \pm 0.164	26	3.483 ^b
1.0	1.093 \pm 0.140	1.000 \pm 0.129	70	4.650 ^c
2.0	1.011 \pm 0.146	1.000 \pm 0.146	63	0.496
5.0	0.965 \pm 0.152	1.000 \pm 0.138	17	0.787

^a The relative $^{45}\text{Ca}^{2+}$ effluxes, given plus or minus the standard deviations (m \pm SD), are referred to the mean value of control condition. N is the number of paired samples (field and control) used in the statistical analysis (t-test).

^b $p < 0.005$.

^c $p < 0.005$.

bathed in physiologic solution. The field effects observed previously were not altered by cyanide treatment, which strongly suggests that the $^{45}\text{Ca}^{2+}$ effluxes from the cerebral tissues are independent of any ongoing metabolism.

Cats have also been exposed to 147 MHz fields of power density 1 mW/cm², amplitude-modulated at brain wave frequencies. A strong influence on spontaneous and conditioned EEG patterns were observed. The hypothesis was offered that the weak electrical forces induced in the brain were modifying the excitability of the central neurons and that these changes were reflected in the recorded transient EEG episode.

Experiments have also been performed using 450 MHz radiation amplitude modulated at 16 Hz to exposed chick brain (Table 3). Again it is important to

note that significant increases in $^{45}\text{Ca}^{2+}$ efflux occurred at exposure levels of 0.5 mW/cm² and 1.0 mW/cm², but did not occur at the higher exposure power densities of 2 and 5 mW/cm².

In the laboratory of NIEHS (3), the spinal cords of cats were directly exposed to 2450 MHz CW microwave radiation in order to study the effect on reflex response and synaptic function (Fig. 2). The exposure power densities were 10 and 20 mW/cm². The exposure period was for 30 min and the control period was 30 min.

The sciatic nerve was stimulated by 0.05 msec, 2.0 V, pulses delivered from pulse generator. The stimuli consisted of short trains of nine pulses at 500 Hz, repeated at 5-sec intervals (Fig. 3). The first response to such a series of stimuli represents a pure monosynaptic reflex, the second and third re-

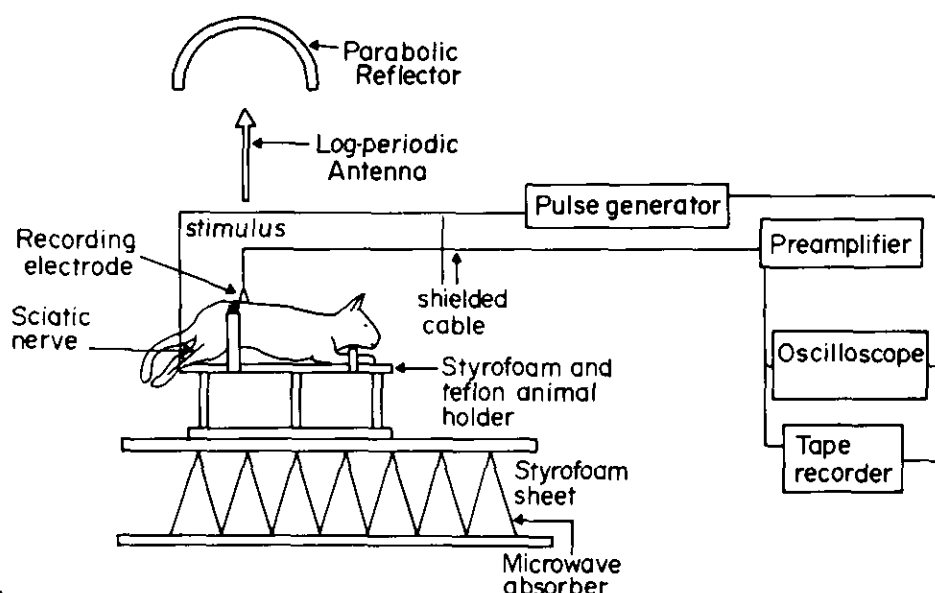


FIGURE 2. Cat positioned in animal holder during microwave irradiation with instrumentation.

sponses show facilitated synaptic transmission, and the last in the train are also influenced by fatigue of synaptic transmission. Multiple stimuli therefore allow the assay of these modifications of synaptic function. Blocks of 50 reflexes evoked in this manner in a period of 4 min 10 sec constituted an observation period of irradiation. Potentials recorded from the ventral root were amplified 500 to 2000 times at a passband of 0.3 to 10,000 Hz and displayed on an oscilloscope, as well as stored on magnetic tape by a portable tape recorder. The recordings were later played back, averaged by a computer of average transients, and plotted by a X-Y recorder (Fig. 3).

The results of the experiment are shown in Tables 4 and 5. For each animal, the possible effect of irradiation on reflex response was evaluated three ways. (1) The average effect, i.e., the average of all responses during the exposure period, was compared with the corresponding average during control periods. (2) The within-period effect, i.e., the average difference between the final and initial readings in each exposure period (EE), was compared to the corresponding average difference during the control period (CC). (3) The between-period effect, i.e., the average difference between the first reading in each exposure period and the final reading in the immediately preceeding control period (CE), was compared to the corresponding average change from exposure to control period (EC). The significance of these effects was assessed by two-sided Wilcoxon signed-rank tests. In the 10 mW/cm²

exposure tests, statistical examination of the results indicate that microwave irradiation may weakly enhance synaptic transmissions in the spinal cord. In five of the six experiments, the mean of all reflexes measured during irradiation exceeded those measured in the control state for the first peak. Moreover, for both peaks the change in response from control to exposure periods appeared to exceed the corresponding change from exposure to control periods (Table 4). However, since the significance was marginal and the experimental protocols were variable, a second series of experiments were undertaken.

In these final six experiments, the incident power density was increased to 20 mW/cm². Nevertheless, in these experiments, there was little evidence of the effects which had been observed in the 10 mW/cm² exposures. Moreover, the slight within-period effect that was seen for the first peak could be attributed to the small temperature variations. In two experiments (18 and 19), the control of temperature proved inadequate, and temperature tended to rise (mean change = 0.325°C) during control periods and to decline (mean change = 0.26°C) during exposure periods. While inadvertent, these variations permitted us in the same experiment to examine separately the effects of temperature change and radiation by analysis of covariance techniques. These procedures indicated that when temperature differences were taken into account, there was little evidence that the radiation was affecting the reflex response other than through the heating process.

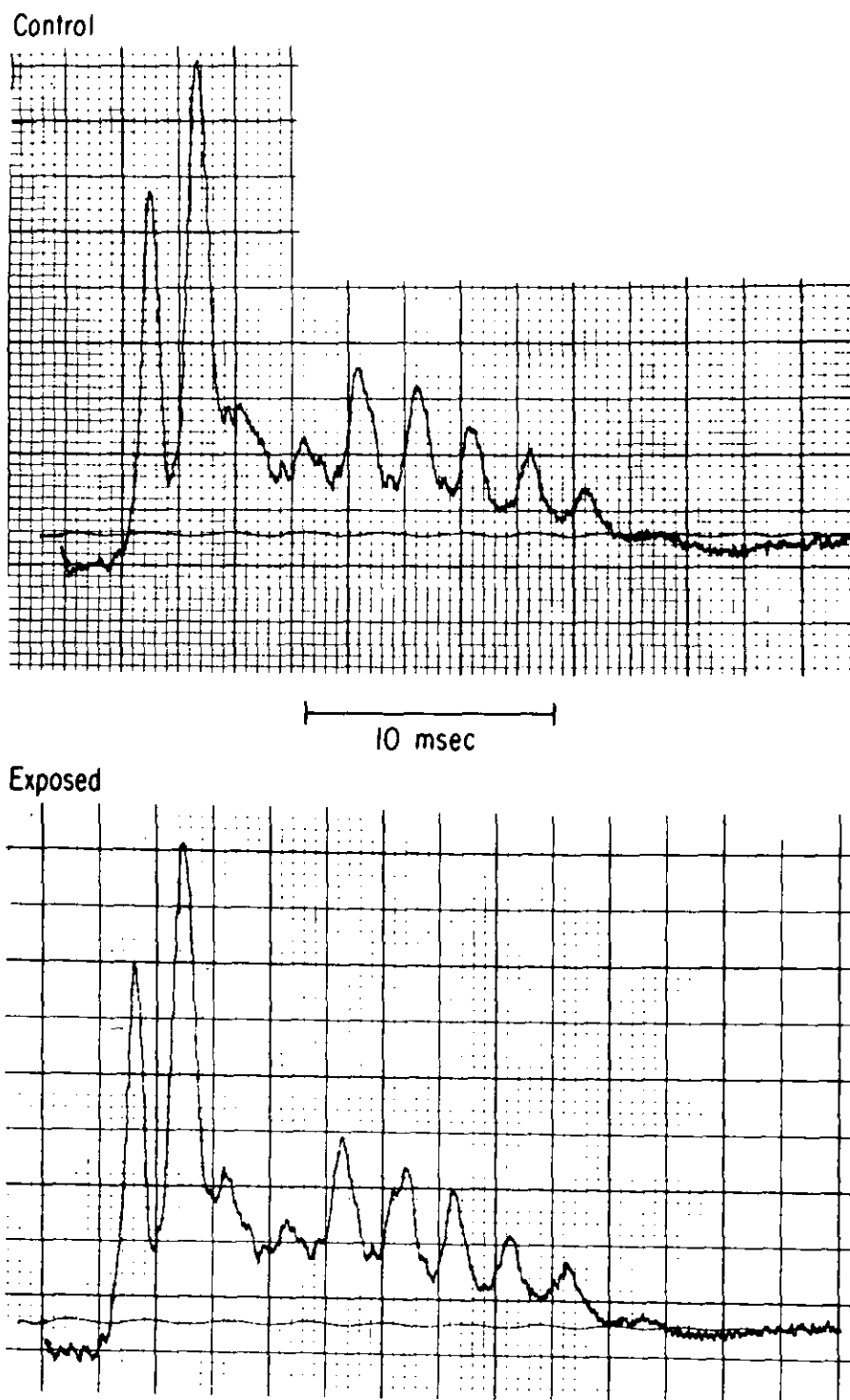


FIGURE 3. Action potentials from a cat's spinal cord after stimulation by a short train of 9 pulses at 500 Hz.

Table 4. Effect of irradiation on reflex response in the first series of experiments.^a

Experiment	Control	Exposed	Average effect (exposed-control)	Within-period effect (EE-CC)	Between-period effect (CE-EC)
First peak					
5	1.89 (8)	2.14 (7)	+ 0.26	0	± 0.60
7	2.04 (10)	2.50 (10)	+ 0.46	+ 1.10	+ 0.60
8	0.63 (8)	0.88 (5)	+ 0.25	+ 0.04	+ 0.16
9	2.72 (13)	2.91 (11)	+ 0.19	+ 0.40	+ 0.21
11	2.04 (11)	1.99 (8)	- 0.05	- 0.11	+ 0.36
12	0.62 (18)	0.64 (15)	+ 0.02	- 0.05	- 0.02
Significance of results			<i>p</i> = 0.094	N.S.	<i>p</i> = 0.062
Second peak					
5	0.62 (8)	0.57 (7)	- 0.05	- 0.03	- 0.03
7	4.10 (10)	4.35 (10)	+ 0.25	+ 0.62	+ 0.88
8	0.75 (12)	0.79 (10)	+ 0.04	- 0.17	+ 0.07
9	2.63 (13)	2.69 (11)	+ 0.06	+ 0.18	+ 0.07
11	1.82 (11)	1.73 (8)	- 0.09	+ 0.08	+ 0.22
12	0.52 (18)	0.54 (15)	+ 0.02	+ 0.05	+ 0.01
Significance of results			N.S.	N.S.	<i>p</i> = 0.094

^a Incident power density = 10 mW/cm². Exposure periods were of variable duration. Numbers in parentheses refer to total number of observations. Within- and between-period effects are defined in text. N. S. = not significant.

Table 5. Effect of irradiation on reflex response in the second series of experiments.^a

Experiment	Control	Exposed	Average effect (exposed-control)	Within-period effect (EE-CC)	Between-period effect (CE-EC)
First peak					
1	0.44 (15)	0.42 (12)	- 0.02	+ 0.02	+ 0.04
15	0.89 (15)	0.87 (12)	- 0.01	- 0.01	- 0.02
20	3.41 (15)	3.41 (12)	0	+ 0.31	+ 0.20
18	0.78 (12)	0.85 (15)	+ 0.07	+ 0.21	- 0.14
19	0.69 (11)	0.75 (15)	+ 0.06	+ 0.16	- 0.16
21	0.80 (12)	0.58 (15)	- 0.23	+ 0.25	+ 0.40
Significance of results			N.S.	<i>p</i> = 0.062	N.S.
Second peak					
1	1.54 (15)	1.40 (12)	- 0.14	- 0.04	+ 0.22
15	1.14 (15)	1.17 (12)	+ 0.03	+ 0.08	- 0.05
20	3.33 (15)	3.23 (12)	- 0.10	- 0.03	+ 0.47
19	1.34 (11)	1.35 (15)	+ 0.01	+ 0.12	+ 0.04
21	0.57	0.49 (15)	- 0.07	+ 0.05	+ 0.14
Significance of results			N.S.	N.S.	N.S.

^a Incident power density = 20 mW/cm². Exposure periods were of uniform duration. Experiments 1, 15, and 20 began and ended with a control period; the other three began and ended with an exposure period. There was no second peak data for experiment 18. Numbers in parentheses refer to total number of observations. Within- and between-period effects are defined in text. N. S. = not significant.

Only the first and second reflex responses in the trains were analyzed statistically. However, from inspecting records there appeared to be no change in the amplitudes of the late responses in the trains either (Fig. 3). It seems, therefore, that the degree of fatigue of synaptic transmission was not influenced by the irradiation.

Project 2. EEG Investigations in Animals Exposed to Microwave Radiation

Research to determine the effects of microwave radiation on EEG has been conducted by Lawrence

Rosenstein of the Environmental Protection Agency (EPA). Sprague-Dawley rats were exposed at 12 days after breeding to 425 MHz radiation at a power density of 10 mW/cm² or at 6 days after breeding to 2450 MHz radiation at a power density of 5 mW/cm². The exposure continued through parturition, at which time the offspring were irradiated through 92 days of age. The 2450 MHz exposure group contained 12 dams and the 425 MHz group contained 6 dams with sham controls for each frequency having identical population numbers.

At 140 days of age, rats from both the 425 MHz and 2450 MHz exposure groups were evaluated for neurological deficits. The electrodiagnostic techniques used were measurements of spontaneous

electrical activity (the electroencephalogram or EEG) and the visual evoked response (VER) using a photostimulus.

Three derivations were used for recording the EEG and the VER. They were the right occipital versus the midfrontal, left occipital versus the midfrontal, and right versus left occipital. Histogram and power spectral analyses were performed on spontaneous EEG segments appearing to be free of artifact. The VER was analyzed using signal averaging techniques.

For both exposure regimes, no statistical difference could be detected between controls and treated rats, particularly with the typical clinical frequency bands (α , δ , θ , β). This was true for the time interval and power spectral analyses. Using stepwise discrimination analysis for the VER, it also was not possible to discern any significant difference between control and treated groups.

Project 3. Study of Effects of Microwaves on Behavior of Animals, Their Conditioned Reflex Activity and on Chemical, Cytochemical, and Immunological Properties of Blood

Lawrence Reiter of EPA used Sprague-Dawley rats which were treated as specified in Project 2 to study the effects on reflex development and locomotor activity. Reflex development including startle response and righting reflex as well as age at eye opening were measured in neonatal animals during the first three weeks of life. No treatment differences were observed at either frequency.

Locomotor activity was measured in adult animals in a residential maze at both 120 and 240 days of age. The residential maze allows for the measurement of ambulation over extended periods of time (either two days at 120 days of age or one day at 240 days of age). No consistent effects on locomotor activity were observed with either treatment.

Michael Gage of EPA has studied the effects of single exposure to 2450 MHz microwave irradiation on rat behavior. Eight adult, male, Sprague-Dawley rats weighing between 284 and 439 g were subjects in this experiment. All rats but one had been exposed many times to microwaves over a wide power density range before the data reported here were collected. Rats were irradiated individually with 2450 MHz CW microwaves in an anechoic chamber under far field conditions. During exposures, an environmental temperature of 22°C and a relative

humidity of 50% were maintained by a feedback control system. The power densities used in the exposures were 0, 0.5, 1, 5, 10, 15, or 20 mW/cm² for overnight periods lasting 15 hr and 0, 0.5, 1, 5, 10, 15, 20, 25, or 30 mW/cm² for periods lasting 55 min. All rats were exposed to every level of exposure for each of the durations.

The behavioral test used was a fixed ratio schedule of reinforcement. The animals were trained to alternately press each of two levers on the front panel of an operant conditioning chamber a fixed number of times to receive a 45 mg food pellet. Five of the rats were required to alternate between the levers 33 times and the other three 11 times for each food pellet. The rats had extensive practice performing the alternation task before the microwave exposures were begun. Behavior testing sessions lasted one half hour and were conducted daily. Behavior testing of exposed rats occurred 5 to 10 minutes after irradiation was terminated.

The results of this experiment indicated that microwave exposure can produce alterations in learning behavior of animals in direct relation to power density of exposure (Fig. 4). Increased power densities led to decreased performance. Microwave exposure did not alter the pattern of lever pressing. The behavioral decrement was more pronounced after 15 hr exposure than after exposures lasting only 55 min. Exposures to 15 and 20 mW/cm² for 15 hr significantly suppressed the rate of bar press alternations, but exposures to the same levels of microwaves for 55 min did not suppress the behavior to such a large degree. However, there was a trend towards decreased behavioral performance after both exposure durations which began with power densities as low as 5 mW/cm².

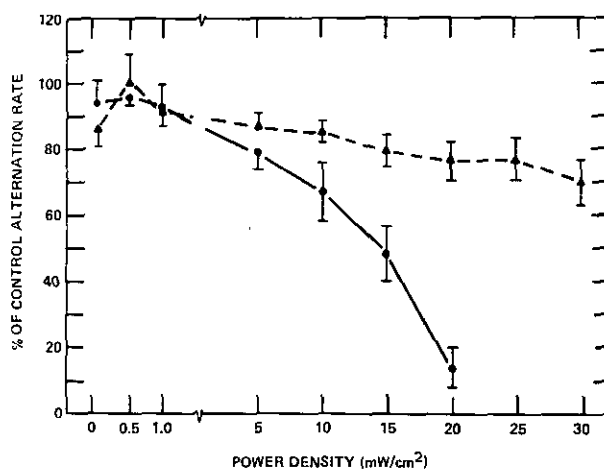


FIGURE 4. Mean and standard deviation of alternation rates, expressed as percent of control rates, of all rats exposed to a range of power densities of microwaves for (▲) 55 min and (●) 15 hr.

W. D. Galloway of the Bureau of Radiological Health has exposed the heads of six rhesus monkeys to 2450 MHz CW radiation (4). Duration of exposure ranged from 2-40 min. Experimental sessions were conducted daily. Subjects were adapted to restraints and trained to press a lever for food reward. Four subjects were entered into the discrimination study, and two subjects were trained in the repeated acquisition experiment. It was determined that for the short term exposures an integral dose of approximately 20-30 mW/g of brain weight were required to effect behavioral changes when the energy is confined to the head of the subject.

Research performed jointly by Guy at the University of Washington, Seattle, Washington and McRee, McConnell, and Faith of NIEHS was designed to determine the effects of chronic exposure on the pathology, hematology, and immunology of the rabbit. Eight adult New Zealand rabbits were used in this experiment, four exposed animals and four control animals. The rabbits were exposed to 2450 MHz at a power density of 10 mW/cm², 23 hr/day for 6 months. At the end of the 6-month exposure period, blood was taken from the animals and analyzed. The clinical chemistry and hematology were both performed (Tables 6 and 7). Using a two-sided Mann-Whitney U-test to evaluate significance, the albumin, calcium, and eosinophil percentages were lower in the exposed animals.

Necropsies were performed on all animals and tissues for histopathology were fixed in 10% buffered neutral formalin. Tissues selected included tongue, esophagus, trachea, lung, heart, liver with gall bladder, stomach, small and large intestine, spleen, thymus, kidney, urinary bladder, testes, skin (ear), brain, thyroid, pancreas, adrenal, pituitary, sternum (for bone marrow) and muscle (thigh). Organ weights were obtained on the heart, lung, liver, kidney, adrenal, thyroid, pituitary, brain and testes. A portion of spleen was taken aseptically for immunological studies. No lesions were observed at necropsy. Microscopic examination of formalin fixed tissues did not show any lesions referable to microwave exposure. No significant differences were observed between the organ weights of the exposed and control animals. Bone marrow examinations showed an abnormal myeloid/erythroid ratio when exposed animals were compared to control. The mean myeloid/erythroid ratio of the exposed and control animals were 1.80 ± 0.15 and 1.20 ± 0.22 , respectively.

The spleens of the animals were used to obtain lymphoid cells in order to study the effects on immunological response. Three mitogens, phytohemagglutinin (PHA), concanavalin A (ConA), and pokeweed mitogen (PWM) were used to stimulate the cells. The rate of cellular DNA synthesis was measured by the incorporation of ³H-thymidine.

Table 6. Clinical blood chemistry in the rabbits exposed for six months.

Test units	Exposed rabbits, X \pm S	Control rabbits, X \pm S	Significance level
Prombthrombin time, sec	11.3 \pm 1.3	11.2 \pm 0.6	N.S.
Partial thromboplastin, sec	21.0 \pm 2.2	20.8 \pm 2.6	N.S.
Fibrinogen (Clauss), mg/dl	232 \pm 60	281 \pm 78	N.S.
Fibrogen degradation, μ g/dl	<10	<10	N.S.
Sodium, mg%	143.0 \pm 0.8	143.5 \pm 1.3	N.S.
Potassium, mg%	4.1 \pm 0.2	4.3 \pm 0.2	N.S.
Chloride, mg%	105.5 \pm 4.4	104.8 \pm 1.7	N.S.
Carbon dioxide, mg%	19.3 \pm 4.3	19.3 \pm 3.0	N.S.
Ion gap	18.3 \pm 1.0	19.5 \pm 3.3	N.S.
Protein, g/dl	6.1 \pm 0.3	6.3 \pm 0.3	N.S.
Albumin, g/dl	3.7 \pm 0.1	3.9 \pm .05	0.046
Calcium, mg/dl	13.5 \pm 0.3	14.1 \pm 0.2	0.020
Total bilirubin, mg/dl	0.20 \pm 0	0.25 \pm 0.06	N.S.
Urea nitrogen, mg/dl	17.8 \pm 3.0	20.8 \pm 6.2	N.S.
Glucose, mg/dl	107.3 \pm 16.8	122.5 \pm 16.6	N.S.
Creatinine, mg/dl	1.12 \pm 0.15	0.98 \pm .10	N.S.
Alkaline phosphatase, units	30.8 \pm 9.5	31.0 \pm 4.2	N.S.
SGOT, units	10.0 \pm 4.7	8.5 \pm 3.7	N.S.
LDH, units	201 \pm 68	199 \pm 146	N.S.
Uric acid, mg/dl	0.65 \pm 0.1	0.75 \pm 0.1	N.S.
Cholesterol, mg/dl	35.0 \pm 11.8	27.8 \pm 23.7	N.S.
Triglycerides, mg/dl	107.5 \pm 108.9	77.8 \pm 10.9	N.S.
Cholinesterase, units	0.64 \pm 0.04	0.79 \pm 0.54	N.S.
T4 by radioimmunoassay	3.2 \pm 1.0	3.9 \pm 1.3	N.S.
Cortisol, μ g/dl	2.5 \pm 3.5	2.7 \pm 3.0	N.S.
Glutathione concentrate, mg/100 ml RBC	69.6 \pm 6.2	72.6 \pm 14.3	N.S.

Table 7. Hematological and urine parameters measured on the rabbits.

Test units	Control rabbits, $\bar{X} \pm S$	Exposed rabbits, $\bar{X} \pm S$	Significance level
Blood			
WBC $10^9/\text{mm}^3$	9.1 ± 1.7	7.7 ± 0.8	N.S.
RBC, $10^6/\text{mm}^3$	6.32 ± 0.47	6.14 ± 0.38	N.S.
Hemoglobin, g/dl	13.6 ± 0.7	$13.2 \pm .08$	N.S.
Hemocrit, %	38.5 ± 1.3	37.8 ± 0.5	N.S.
MCV, μ^3	61.5 ± 3.0	61.5 ± 3.8	N.S.
MCH, pg	21.5 ± 0.6	21.5 ± 1.2	N.S.
MCHC	35.7 ± 1.4	34.9 ± 0.3	N.S.
Platelet count, $10^9/\text{mm}^3$	367 ± 104	369 ± 75	N.S.
Lymphocyte, %	50.0 ± 14.4	35.8 ± 22.2	N.S.
Neutrophil, %	42.0 ± 13.6	58.5 ± 22.4	N.S.
Monocyte, %	3.8 ± 3.0	3.0 ± 1.8	N.S.
Eosinophil, %	1.75 ± 0.96	0.25 ± 0.5	0.034
Basophil, %	1.25 ± 0.96	2.5 ± 1.9	N.S.
Urine			
Catecholamines, $\mu\text{g}/\text{sample volume}$	0.91 ± 1.41	1.05 ± 1.1	N.S.
Creatinine, $\text{mg}/\text{sample volume}$	0.91 ± 0.73	0.79 ± 0.18	N.S.

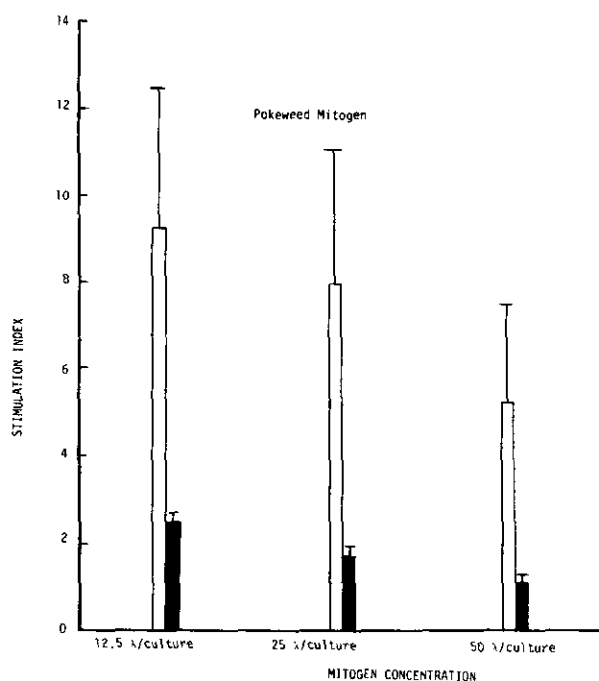


FIGURE 5. Comparison of stimulation index for (■) exposed and (□) control lymphoid cells.

Although a reduction in stimulation occurred in both PHA and ConA stimulation, these differences were not statistically significant due to the small number of animals and variability in the data. However, in the case of pokeweed mitogen, the stimulation in the exposed animals were statistically ($p < 0.05$) different from the control animals (Fig. 5). The stimulation index is derived by dividing the counts per minute of triplicate mitogen stimulated cultures by the mean counts per minute of triplicate non-

stimulated cultures.

Based on the limited data obtained in this study, it may be concluded that microwave exposure suppresses, at least slightly, immune competence. Based on results reported, microwaves most likely suppress both T- and B-cell populations. PHA and ConA are strict T-cell mitogens, while PWM is mitogenic for both T- and B-cells. While the results of this study indicate that microwaves may be immunosuppressive, they are not conclusive due to the small number of animals and the limited variety of immune response parameters utilized.

In summary, results of studies relative to projects associated with the collaborative research to determine the biological effects of nonionizing radiation have been presented. Since the primary objective of this report is to present progress, details of experimental design, exposure techniques, and energy absorption are not given in the paper. Some of the studies have been completed and the results have either been published or are in press. References are given to the finished work. Other studies have not been completed and the results reported here are the findings at the time of the symposium.

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